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ATMOSPHERE POLLUTION ASSESSMENT CAUSED BY ENTERPRISES EMISSIONS OF INDUSTRIAL CENTRES OF IRKUTSK REGION

Speciality 25.00.36 - Geoecology

AUTHOR'S ABSTRACT
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GENERAL DESCRIPTION OF WORK

Relevance of the topic

At present, air pollution emissions from industrial enterprises covers significant land area from cities and metropolitan areas till entire regions. There is an acute problem of air pollution in the Irkutsk region - a region, which is the industrial center of Eastern Siberia. With large reserves of natural resources, Irkutsk region occupies a leading position among the other regions of the Siberian Federal District in the chemical and metallurgical industry, mechanical engineering, mining, power generation, aluminum, pulp. Such a variety of industrial sectors that are present in the region, is reflected in the diversity of impacts in the environment, first and foremost, on the air.

According to statistical data published annually by the Ministry of Natural Resources, Irkutsk region occupies the ninth place (according to data for 2014) among other 84 subjects of the Russian Federation on volume of emissions into the air (825 thous. tonnes), after the Krasnoyarsk Kray, Kemerov and Sverdlov regions and a number of other subjects. It is worth noting that during the last sixteen years, the largest part of emissions come from stationary sources (over 77%), the emissions from mobile sources make up just over 20% of the total amount entering of pollutants the atmosphere.

The most environmentally disadvantaged are large industrial centers of the region, such as Irkutsk, Angarsk, Bratsk, Shelekhov, Zima. These settlements for over 10 years, every year are included in the priority list of cities with the highest level of pollution formed by the value of air pollution index (API).

In this regard, an important question is the diagnosis and prediction of atmospheric pollution levels for the development of recommendations for the improvement of production technology, and take the necessary actions to lessen the pressures on the atmosphere. Special attention should be paid to the main source of pollutants in the ambient air on the territory of the Irkutsk region - stationary sources of industrial enterprises.

Currently, observation of the content of pollutants are carried out at points monitor the air quality. The data are obtained in the course measuring do not give a complete picture of air pollution, as only represent values of concentrations of the individual components of the composition of the air with a limited number of observations, either on the local terrain point.

In addition to regular systematic observations, which carrying out in the framework of air pollution monitoring of the Irkutsk region, there are a number of studies devoted to the study of air pollution or some large industrial enterprises, or aimed at assessing contamination by studying the chemical composition of atmospheric precipitation.

The most revealing to assess the level of air pollution, author believes, is the calculation of absolute concentrations of pollutants in the atmosphere and determination (subject to climatic features of the area), the duration of exposure of hazardous concentration of pollutants on the surrounding landscapes and population.

Objective: To assessment of the air pollution level created by the emissions of stationary sources of enterprises industrial centers of the Irkutsk region, taking into account climatic factors that influence the scattering and accumulation of pollutants.

To achieve the objective has been set the following *tasks*:

- create a database of 8-term long-term observations, conducted at meteorological stations of the Irkutsk region; carry out their statistical processing;
- calculate the stability of wind characteristics;
- construct climate scattering ellipses;
- create the inventory database of stationary sources of industrial enterprises;
- calculate the absolute concentrations of pollutants;
- calculate the frequency of exceeding sanitary and hygiene standards prescribed for pollutants;
- construct schematic maps of isolines of absolute concentrations of pollutants;
- construct schematic maps of isolines of frequencies of exceeding hygienic standards of pollutants;
- analyze the dynamics of concentration fixed on the observation points of atmospheric air pollution on the territory of the Irkutsk region;
- conduct a comparative analysis of calculated and field data characterizing the air pollution level.

The factual material. Thesis is based on the data the 8-term multiyear (1995-2014) observations on temperature and wind velocity vector 22 hydrometeorological stations. To calculate the air pollution levels using inventory data of 20 000 stationary sources of enterprises industrial centers in the Irkutsk region: the mutual arrangement of the sources (coordinates), the source height (pipe), the radius of the mouth of the source, temperature and output velocity of the gas mixture, the intensity (power) source. Calculation is carried out for the 100 names of pollutants. For verification of obtained data are used the data of field observations on points tracking air pollution located in the cities of Irkutsk and Shelekhov for the period of 2000-2015 and 2008-2015 respectively.

Research Methods. For the processing of time series of meteorological data used methods of mathematical statistics. In particular, for the preparation of data as input in atmospheric pollution levels calculation models was used calculates the performance of position and spread.

The calculation of absolute concentrations of contaminants was performed using standard empirical model based on the OND-86 and applied in software "Ecolog". To determine the frequency of exceeding hygienic standards of pollutants was used semi-empirical mathematical model that takes into account the climatic features of the area and based on the analytical solution of the transport equation and the turbulent diffusion of impurities with the closure on the Integral Distribution Functions of two-dimensional vector wind velocity.

The method of statistical analysis of the concentrations of the data obtained the monitoring stations for air pollution, allowed to reveal posts with the highest frequency of recurrence of exceeding sanitary and hygiene standards of air quality, as well as to analyze the dynamics of average and maximum concentrations on the territory of Irkutsk and Shelekhov.

For graphical representation of the research results were used software packages Surfer, Quantum GIS, AutoCAD.

The scientific novelty of this work consists in the following:

- for the first time in the Irkutsk Region on the basis of multiyear meteorological data (1995-2014) are constructed climate ellipses characterizing the scattering of the wind velocity vector components and determine the main directions of transport of pollutants in the atmosphere;

- for the first time on the basis of current data on existing stationary sources of enterprises industrial centers, in general for the the territory of the Irkutsk region, were calculated absolute concentrations of contaminants, and frequencies of exceeding hygienic standards;

- on the basis of the obtained results drawn up maps of isolines of the absolute concentration of polluting substances and frequencies of exceeding hygienic standards for the Irkutsk Region;

- for the first time analyzed the representativeness of the existing scheme of location of monitoring posts for air pollution in terms of homogeneity obtained in the course of field observation data and the possibility of assessing the contribution of stationary sources in air pollution.

The practical significance of research work consists in the use of materials research by the Office of Ecology of Committee of urban arrangement of Irkutsk City Administration to adopting constructive measures to improve the environmental situation in Irkutsk; FSBIS «Institute of Geography V.B. Sochava» SB RAS for compilation of environmental atlas of Irkutsk and Lake Baikal; JSC "East-Siberian trest construction and engineering surveys" for the analysis of air pollution levels in the areas of engineering and environmental surveys; and Irkutsk State University for the preparation of lectures on disciplines: "Environmental monitoring", "Industrial ecology", "Mathematical modeling in environmental objectives"that is confirmed by implementation acts.

The main provisions that taken out on defence:

1. Climatic conditions of the Irkutsk region in the winter is not favorable for scattering of emissions entering in the atmosphere from stationary sources of industrial enterprises, the most favorable for the scattering are the spring months, as evidenced by modeling of the climatic scattering ellipses.

2. On the the residential areas of the Irkutsk region concentrations of some pollutants in the 10-20 times higher than the standards set for them, which is confirmed by calculations based on empirical mathematical model and the mapping of the study area for the largest absolute concentrations.

3. The exposure duration on living organisms of pollutants whose concentrations exceed the hygienic standards, reaches 600-700 hours per month, which is con-

firmed by calculations based on semi-empirical mathematical model and the mapping of the study area in frequency of exceeding hygienic standards.

4. The existing scheme of location of posts of air pollution monitoring in the region complicates the identification of the contribution of stationary sources ambient air pollution, monitoring of completeness of the implementation of measures under adverse weather conditions, as well as irregularities prescribed for businesses maximum permissible emissions, as confirmed by the study of the homogeneity of field data and a comparative analysis with the results of the calculation.

The authenticity of the results obtained is justified:

- large sets of used data of 8-term meteorological observations (1995-2014), that ensuring the stability of climatic characteristics on the considered seasons;
- using in the study of two proven models: 1) empirical model (on the basis of the OND-86); 2) a mathematical model based on the solution of the transport equation and the turbulent diffusion of impurities with the closure in the Integral Distribution Functions of two-dimensional vector wind velocity;
- qualitative and quantitative proximity of calculated characteristics with data of field observations from points for monitoring pollution ambient air;
- scientific publications and acts on implementationg.

Author's contributions. The author created data array of 8-term observations of 22 meteorological stations of the Irkutsk region for the period 1995-2014, was carried out their statistical processing, on results of which conclusions were made about the scattering ability of the atmosphere of the territory. A inventory database of stationary sources of industrial enterprises located in the Irkutsk region was created. By using mathematical models were calculated: 1) the absolute concentrations of the ingredients; 2) the duration of the environmental impact of pollutants exceeding the standards. On the basis of the conducted data the mapping of territory study on the level of air pollution has been carried out. A comparative analysis of the calculated data with the data, fixed at the posts for air pollution monitoring. The author personally obtained all the main practical results of work.

Work approbation. 23 works on the thesis topic were published, 6 of them - in the list of journals HAC, 2 - in the Journals of Scopus.

Some results of the dissertation were reported at 19 Russian and international conferences, including:

1. I International scientific-practical conference «The global dimension of modern science and education» (Rostov-on-Don, 2011);
2. Russian National Contest of research works of graduate students in the field of Earth Sciences (Томск, 2012);
3. VII Workshop of Russian young scientists "Problems of sustainable development of the region» (Ulan-Ude, 2013);
4. XXVI International scientific-practical conference "Ecology. Manufacturing. Society. Human» (Penza, 2014);
5. International scientific-practical conference "Innovative science and modern society» (Ufa, 2015);

6. VII International Russian-German summer school «Ecology of large water bodies and their watersheds» (Irkutsk, 2015);

7. 16th International Multidisciplinary Scientific GeoConferences SGEM «The 16th Geoconference on energy and clean technologies» (Bulgaria, 2016).

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1. Grant 2012-09-01 for supporting research work of graduate students and young employees of ISU «Air pollution caused by industrial enterprises of Irkutsk city», 2012;

2. Grant 091-14-220 for supporting research work of graduate students and young employees of ISU «Air pollution caused by industrial enterprises that located on the territory of Irkutsk agglomeration», 2014;

3. Grant RFBR 16-35-00185 Modeling of distribution of man-made contaminants coming from stationary sources of industrial enterprises of the Irkutsk region in the air, 2016-2017.

The author received 4 act on the implementation of the research results issued by the JSC "East-Siberian trest construction and engineering surveys", Office of Ecology of Committee of urban arrangement of Irkutsk City Administration, FSBIS «Institute of Geography V.B. Sochava» SB RAS, Irkutsk State University.

Thesis structure. The work consists of introduction, three chapters with the findings for each chapter, conclusion, list of references and appendices. Contains 183 pages of text, including 40 tables, 57 figures and bibliography - 198 titles.

SUMMARY OF THE THESIS

The first chapter is devoted to a review of the literature on the topic of research, that cover the existing approaches to the definition of the atmosphere's self-purification, regulation of air quality, as well as methods for air pollution modeling.

Section 1.1. The brief review of the existing work in the field of air pollution studies. Emphasizing the work of M.E. Berlyand, E.Yu Bezuglaya, L.R. Sonkin, Yu.A Izrael, G.I. Marchuk, A.E. Aloyan, V.V. Penenko, which are the basis for modern air pollution studies. Also drew attention to the regional studies carried V.K. Arguchintsev, A.V. Arguchintseva, O.V. Stashok, O.G. Netsvetaeva, I.I. Marinaite, E.V. Chipanina, T.V. Khodzher, V.A. Obolkin, V.L. Potemkin, V.L. Makukhin. However, the scientific projects that have been done for the territory of the Irkutsk region, connected with the issue of air pollution, or in terms of the analysis of the chemical composition of atmospheric precipitation, or carried for individual enterprises.

Section 1.2 is devoted to the existing approaches to the valuation of air quality in Russia and several foreign countries, including: Australia, Brazil, Canada, China, European Union, India, Japan, Mexico, South Korea, Thailand, United States. Currently in the world, along with hygiene criteria for air quality established concentration limits for the vegetation, considered the appointment of area (industrial, special protection, etc.). The Russian Federation is mainly used sanitary-hygienic regulation defining the concentrations allowed for the person, and themselves regulations apply to the whole territory of Russia without taking into account regional specificities, level of development of industry in this area, climatic conditions, the existing environment, the presence of protected territories.

Section 1.3. The approaches that used to assess self-purification capacity of the atmosphere was considered. Emphasized the contribution of V.V. Kryuchkov, E.Yu Bezuglaya, A.V. Grigoryan, S.N. Stepanenko in the development of methods of calculation of air pollution potential; T.S. Selegey, Yu.V. Rusanov, O.S. Vizenko, L.P. Sorokina, L.M. Fetisova - calculation methods of self-purification capacity of the atmosphere; I.N. Kuznetsova who created the classification of the atmosphere's self-purification on the basis of meteorological parameter of pollution and forecast adverse meteorological conditions. However, some of the existing methods for assessing the atmosphere's ability to cleanse itself has not been approbation in the Irkutsk region because of the complexity of orography, which impact on the wind's characteristics, leaving against the backdrop of a large scale transfer the local circulation of air masses can occur, which in turn have an impact on the accumulation and dispersion impurities. Therefore, when analyzing a self-purification ability of atmosphere it is important to apply probabilistic and statistical methods for processing of climatic data affecting the dispersion of pollutants and, in particular, wind velocity field.

Section 1.4. Covers methods of modeling the dispersion of pollutants in the ambient air. Special attention is given to different groups of models: empirical, theoretical and semi-empirical; their features, from the viewpoint of consideration of the physical processes and using the mathematical system. Most of the existing models can only calculate the mean or absolute concentrations of contaminants. Along with this interest is the identification of the duration of exposure exceeding the established norms of pollutants concentrations, taking into account meteorological factors and their fluctuations on the study area, which will be implemented in this thesis.

Key findings on the first chapter: The issue of air quality assessment for the territory of the Irkutsk region is still important in terms of finding the absolute concentrations of pollutants in ambient air and frequencies of exceeding sanitary standards. Among the existing mathematical models for calculating best meet to stated tasks - empirical, allowing to calculate absolute concentrations of contaminants and semi-empirical models that take into account the diffusion of impurities during transfer to the atmosphere, taking into account the characteristics of the wind that have high variability that caused by orographic complexity . As a priority criterion of air quality in the study should be taken maximum permissible concentration daily average ($MPC_{d.a.}$) because calculations are made for the residential areas on the basis of emissions data about permanent stationary sources.

The second chapter deals with materials and investigation methods.

Section 2.1. The features of topography and climate of research area - Irkutsk region was considered. It is noted that, due to inhomogeneity of relief the climatic factors characterized territorial variability that affects the accumulation, transfer and scattering of contaminants.

Section 2.2. It discribes methods for studying the possibility for amosphere self-purification of the Irkutsk region, by modeling the scattering wind velocity vector. It is based on data of 8-term observations of meteorological stations located on the territory of 22 settlements of the region for the period 1995-2014. Mathematical statistics method was used for their processing, in particular calculated:

- average of components of wind velocity vector;
- the standard deviation of the wind velocity vector components;
- average of resulting vector of wind velocity;
- average of Scalar wind velocity;
- the asymmetry coefficient of the wind velocity vector components;
- excess for each component of the wind velocity vector;
- correlation coefficient between the components of the velocity vector.

The ratio of the average value of the resultant velocity vector ($\overline{V}_r$) to average of scalar velocity ($\overline{V}_s$) gives us the characteristic that called wind stability. Sustainability wind (q) means the prevalence in the area of the one wind direction over the other. The closer q to "one", the more wind stability. Wind stability at 22 stations located in the territory of the Irkutsk region is calculated using the following formula:

$$q = \frac{\overline{V}_r}{\overline{V}_s} . \qquad (1)$$

For a graphical representation of the possibility of the atmosphere to self-purification was used ellipses of scattering, the center of which is the average value of the velocity vector components and semi-axes values are defined by the standard deviation, reflecting scattering around the center. For ellipses scattering was calculated angle of rotation about the coordinate axes, the ellipticity, which allows to determine the extent to which this scattering vectors is different from the circular, as well as the scattering square of ellipses.

Section 2.3. The characteristic of anthropogenic sources of pollutants to the atmosphere has been given. It was found that most of the emissions (60 to 80%) in the Irkutsk region comes from stationary sources of industrial enterprises. As of 2014 the region has more than 700 industrial facilities, and about 22 thousand stationary sources of air pollution.

With regard to the distribution of emissions among the cities of Irkutsk region, the first place in the number of emitted pollutants into the ambient air takes Angarsk (more than 3000 stationary sources emit more than 260 thousand tons of pollutants). In the second place, according to the annual emission mass is Bratsk (about 500 stationary sources, which emit more than 110 thousand tons of pollutants). The administrative center of the region - Irkutsk, ranks third in the mass of pollutant emitted each year. Number of stationary sources is about 2 thousand, the emission from them is more than 60 thousand tonnes.

Among the industries the highest number of emissions come from the production and distribution of electricity, gas and water; manufacturing; metallurgical production and production of finished metal products. Emissions from these sectors amounted to (in 2014), 389.7 thousand tones, 195.5 thousand tones and 113.1 thousand tonnes respectively. Because the main emission from enterprises of the region necessary on the energy sector objects, natural is the fact that in the composition of pollutants dominated by combustion products, namely: sulfur dioxide, carbon monoxide, nitrogen dioxide, hydrocarbons.

The thesis used the inventory data of the industrial enterprises of large industrial centers of the region. The total number taken into account in the calculation of stationary sources amounted to 20 000. The calculation was performed for more than 100 pollutants emitted by these sources.

Section 2.4. The mathematical models used to calculating were described. Empirical model, which based on the OND-86 was used to calculate absolute concentrations of contaminants. This method is approved at the state level and used in the implementation of regulatory calculations as at the design stage and at the stage of the operation of businesses with sources of pollution.

The method allows calculate the maximum surface concentration of polluting substances (mg/m^3, the share of MPC):

$$C_m = \frac{AMFmn\eta}{H^2 \sqrt[3]{V_1 \Delta T}} \qquad (2)$$

where A – coefficient that takes into account temperature stratification; M *(g/s)* – the amount of harmful substances emitted into the atmosphere per unit of time; F – coefficient reflecting the sedimentation rate of harmful substances in the air; m,n – dimensionless coefficients, taking into account the conditions of output gas mixture from the source of emission; η – dimensionless coefficient taking into account orography of study area; H *(m)* – source height; V_1 *(m^3/s)* – the volume of the gas mixture coming from the source of contamination; ΔT *(^0C)* – difference between gas mixture temperature and the environment.

The second method is a model for calculating the frequency of exceeding hygienic standards polluting substances, by finding the frequency of realization of the winds for the interesting time interval that may lead to the creation of concentrations whose values are above the maximum permissible.

The model is based on the equation of transport and the turbulent diffusion of impurities (3) and its analytical solution proposed by M.E. Berlyand (4).

$$\frac{\partial s}{\partial t} + \upsilon\frac{\partial s}{\partial x} + v\frac{\partial s}{\partial y} + (\omega - \omega_g)\frac{\partial s}{\partial w} + \alpha s = \frac{\partial}{\partial x}k_x\frac{\partial s}{\partial x} + \frac{\partial}{\partial y}k_y\frac{\partial s}{\partial y} + \frac{\partial}{\partial z}k_z\frac{\partial s}{\partial z} + f(x,y,z,t), \qquad (3)$$

where s – concentration of impurities (mg/m^3), υ, v, ω - components of the wind velocity vector projected onto the axis of the local Cartesian coordinate system x,y,z (axis x,y have horizontally directed, axis z – vertically upwards) (m/s), t – time (s), ω_g- speed of gravitational settling of particles (m/s), α - coefficient of impurities decay (s^{-1}), k_x, k_y, k_z - coefficients of turbulent diffusion along the axes *Ox, Oy, Oz* respectively (m^2/s), f – function describing the source of impurities.

$$s = \frac{M(zH)^{\frac{1-m}{2}} z_1^m}{2\mu k_1 \sqrt{\pi k_0 x^3}} \exp\left[-\frac{y^2}{4k_0} - \frac{u_1 z_1^{2-\mu}(z^\mu + H^\mu)}{k_1 \mu^2 x}\right] \times I_{-\frac{1-m}{\mu}}\left[\frac{2u_1 z_1^{2-\mu}(Hz)^{\frac{\mu}{2}}}{\mu^2 k_1 x}\right] \quad (4)$$

where *us* – convective flow of impurity coming from the source into the atmosphere, *M* - source strength, *I* - Bessel function of imaginary argument, $\mu = 2+n-m$, n и m- dimensionless coefficients for interpolation of the vertical profile of the wind velocity and the exchange coefficients, u_1 and k_1 respectively, wind speed and turbulent exchange coefficient, vertically on high z_1; k_0=const, having a length dimension.

Thus, if there are several sources of polluting substances, the impurity concentration is regarded as the sum of equations (4). Further, this sum is limited by norm, in our case, it is $MPC_{d.a.}$. And calculates the maximum value of velocity module (u_k) at each point for each wind direction, in which the criterion is reached ($MPC_{d.a.}$). As a result, from the set of solutions, we choose the its subset that provides violation of the criterion, ie the interval $[0, u_k]$ is sought, in which there is excess of the norm.

The behavior of the wind velocity vector describes theoretical or empirical law. For example, we can use normal distribution to describe the behavior of the wind velocity vector:

$$f(u,v) = \frac{1}{2\pi\sigma_u\sigma_v\sqrt{1-r^2}} \exp\left[-\frac{\xi_1^2 - 2r\xi_1\xi_2 + \xi_2^2}{2(1-r^2)}\right] \quad (5)$$

(2.23)

where $\xi_1 = \frac{(u-\bar{u})}{\sigma_u}, \xi_2 = \frac{(v-\bar{v})}{\sigma_v}$; $\bar{u}, \bar{v}$ - average values of wind velocity vector components; σ_u and σ_v - standard deviations for u and v; r - the correlation coefficient between u and v.

Having integrated the probability density function (5) on the selected subset of wind velocities $[0, u_k]$ we are getting the probability distribution function of the realization of the set wind direction, not exceeding in modulus critical value u_k or frequency of exceeding $MPC_{d.a.}$.

Key findings on the second chapter: the territory of the Irkutsk region is characterized by a heterogeneous, strongly dissected relief, which is reflected on the peculiarities of the climatic conditions, and in the first place, wind characteristics that must be considered when studying the distribution of pollutants. Joint use of two mathematical models allow to estimate the level of air pollution in terms of finding the absolute concentrations and frequencies of exceeding hygienic standards.

In the third chapter the estimation of atmospheric pollution was given.

Section 3.1. The results of the calculation of the stability characteristics of the wind were presented. Highest instability is characterized by the wind in January, with the exception of the station Zheleznogorsk-Ilimskii (*q*=0,8), Mama (*q*=0,7), Kirensk (*q*=0,6). At Zheleznogorsk-Ilimskii station was noted the predominance of the west wind, the repeatability of which in January was 50%, Kirensk station and Mama are characterized by a predominance of north-western direction, repeatability is 65% and 60% respectively. In April, the highest wind stability coefficient was recorded at stations Nizhneudinsk (*q*=0,8), Usolie-Sibirskoe (*q*=0,8), Kirensk (*q*=0,7), Cheremhovo

(q=0,7), Sayansk (q=0,7). This indicates the predominance of one direction in this area, for example, in the Nizhneudinsk station in April is dominated by north-west wind, the repeatability of which is 32 %, at station Kirensk south-west, and Cheremhovo station - north-west, with repeatability of 42 %. In June, the highest wind stability noted at stations Usolie-Sibirskoe, Ust'-Ilimsk, Ust'-Kut, Zheleznogorsk-Ilimskii. It is worth noting that in some stations for all periods (January, April, June) the wind is characterized by the instability. These posts are Angarsk (in January q=0,4, in April – 0,2, in June – 0,1), Balagansk (in January q=0,2, in April – 0,4, in June – 0,3), Irkutsk (in January q=0,3, in April – 0,1, in June – 0,1), Shelekhov (in January q=0,3, in April – 0,4, in June – 0,3). This is due to the predominance in these territories of the two wind directions with approximately the same speed: the north-west and south-east in Angarsk, Irkutsk and Shelekhov and the north and north-west in Balagansk.

For a graphical representation of the possibility of the atmosphere to self-purification was used climate scattering ellipses (Fig. 1, 2, 3). According to received information in January, the most favorable conditions for dispersion of pollutants generated in the area of stations Mama, Kirensk, Zheleznogorsk-Ilimskii, Taishet, Balagansk и Cheremkhovo. The ellipticity of scattering vectors of the wind speed in almost all cases is insignificant, with the exception of the station Balagansk, Zhigalovo, Irkutsk, Taishet, in which coefficient of ellipticity reached a value of 0.7. It is worth noting that at some stations ellipses are shifted from the center in the direction of the prevailing winds, for example, in Irkutsk scattering ellipse is shifted by a preponderance of the north-west direction of the wind. In comparison to the scattering ellipse in April (Fig. 2) and Jun (Fig. 3) January's ellipses indicate the unsatisfactory conditions for dispersion of contaminants in this period. In April, the most favorable conditions for dispersion are created in Cheremkhovo, Mama, Zheleznogorsk-Ilimskii, Saynsk, Tulun, Balagansk, Kirensk. Maximum ellipticity (L=0,6) recorded in Irkutsk, as well as Balagansk, Zhigalovo, Mama, Cheremkhovo, Chelekhov (L=0,7). Also noted offset ellipses dispersion from the center in the direction of the prevailing winds, this situation is observed in almost all stationsEllipses scattering in June (see. Fig. 3) show a decrease in the scattering power of the atmosphere during this period as compared to April, while the degree of dispersion in June is higher than in January. The most favorable conditions for dispersion observed in the northern areas, at stations Ust'-Kut, Ust'-Ilimsk, Mama, Kirensk, as well as Taishet and Balagansk. Maximum ellipticity, according to calculation was marked at stations in Balagansk, Mama, Shelekhov and Irkutsk (L=0,7).

The largest squares of the ellipses dispersion observed in April, the month characterized by activization of cyclonic activity, accompanied by increased wind velocity, as a result created the most favorable conditions for self-purification of the atmosphere. Next largest square followed by ellipsis dispersion wind flow in June, when the wind velocity module is reduced in comparison with April. The minimum value of dispersion ellipses marked in January, when there is a maximum frequency of low velocity of wind, therefore, this period is especially unfavorable to purify the atmosphere.

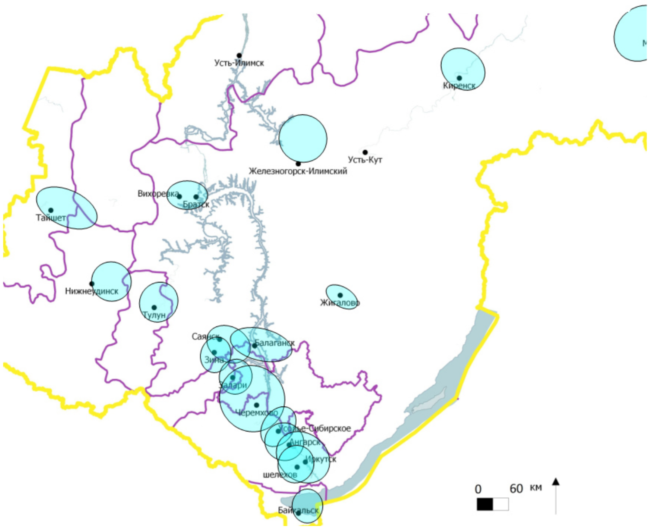

Figure 1 - Climate ellipses scattering of wind flow on the territory of Irkutsk region in January

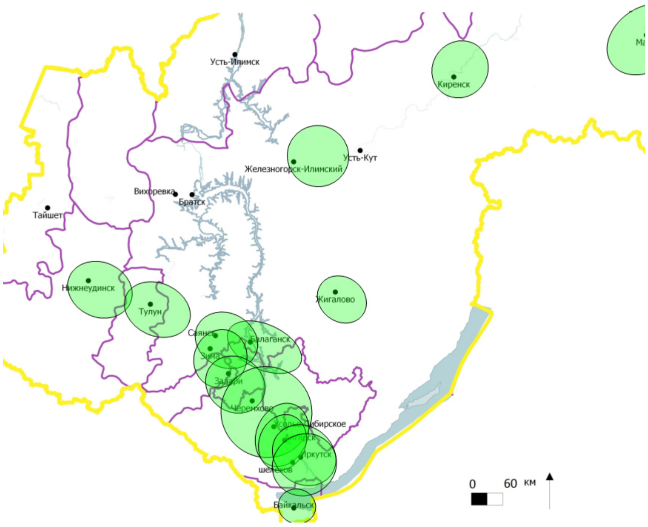

Figure 2 - Climate ellipses scattering of wind flow on the territory of Irkutsk region in April

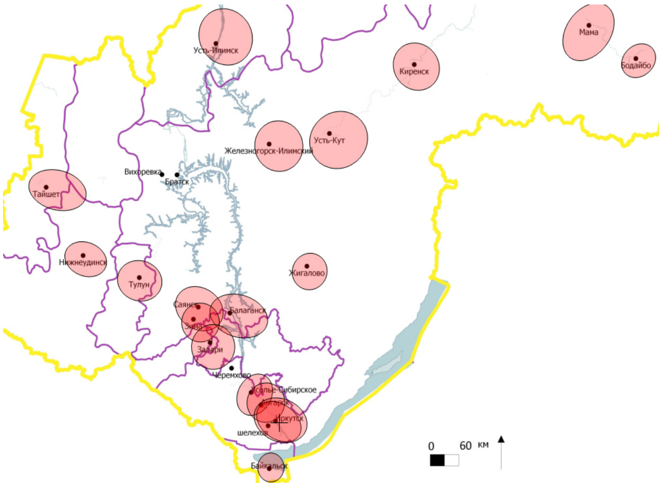

Figure 3 - Climate ellipses scattering of wind flow on the territory of Irkutsk region In June

Section 3.2 The results of the calculation of absolute concentrations by using empirical model were presented. According to calculations, the excess identified in the following substances: nitrogen dioxide, sulfer dioxode, carbon black, inorganic dust with a silicon content of 20-70% and less than 20%, nitrogen oxide, benzo (a) pyrene, oil fly ash, as well as a number of specific substances. Let's present separate results, in particular, for nitrogen dioxide. According to the calculations the exceeding of standards are created on the territory of cities: Irkutsk, Angarsk, Shelekhov, Sayansk, Zima, Ust'-Ilimsk, Bratsk, Tulun, Zheleznogorsk-Ilimskii, Cheremkhovo.

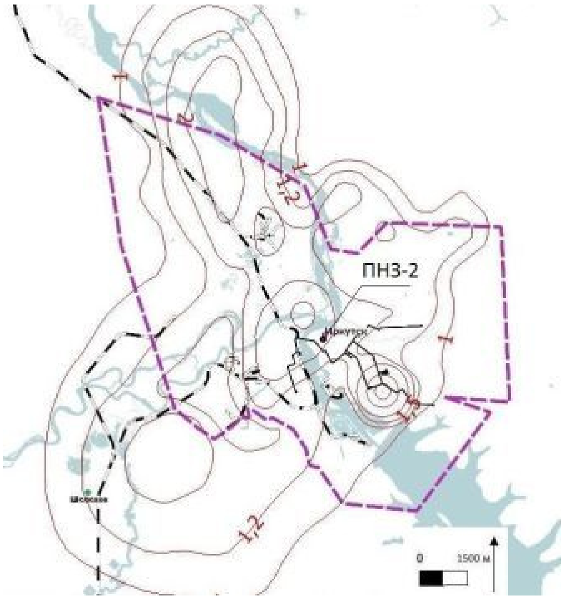

Figure 4 - Schematic map of isolines of absolute concentrations of nitrogen dioxide in the winter time in the city of Irkutsk

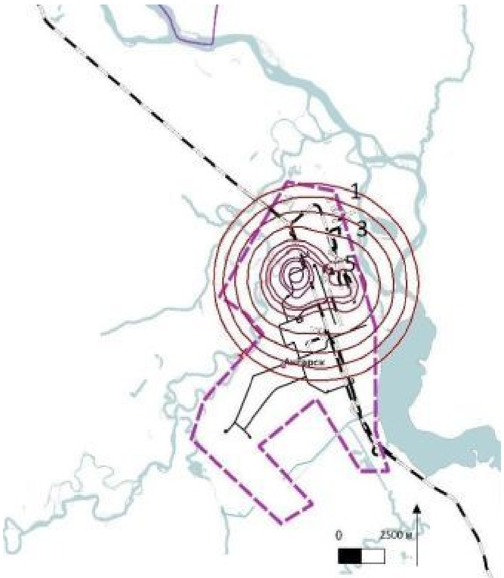

Figure 5 – - Schematic map of isolines of absolute concentrations of nitrogen dioxide in the winter time in the city Angarsk

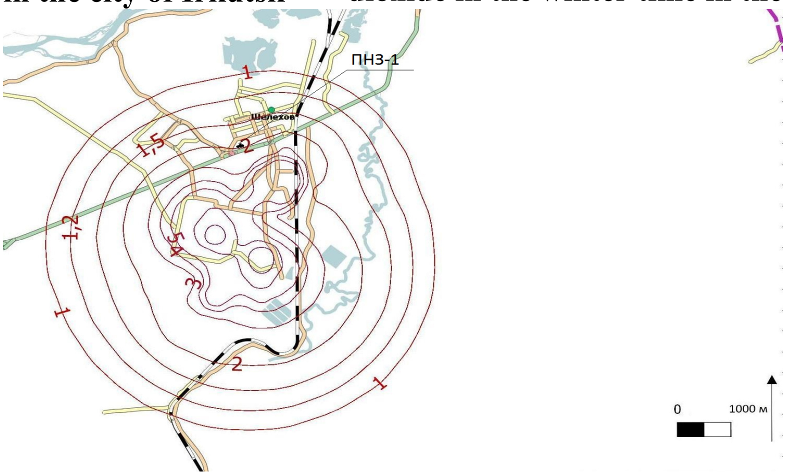

Figure 6 – Schematic map of isolines of absolute concentrations of nitrogen dioxide in the winter time in the city of Shelekhov

The maximum concentration of 20 $MPC_{d.a.}$ are marked in the winter period in the locations of large industrial facilities area, for example, such concentrations were obtained in Angarsk, Shelekhov, Bratsk, in areas where are placed the Angarsk Petrochemical Plant, the Irkutsk Aluminum Plant, Bratsk Aluminum Plant, respectively. In Irkutsk the emissions from stationary sources are located above the town and create a concentration in excess of the established standards for residential areas for nitrogen dioxide in the 9 times (Fig. 4). This maximum occurred in the northern part of the city, in the area of location of large industrial company - Irkutsk Aviation Plant. The maximum concentrations of nitrogen dioxide in the territory of Angarsk and Shelekhov are 20 $MPC_{d.a.}$ and are found in industrial areas of cities. Residential areas of Angarsk is exposed to concentrations as high as the value 9 $MPC_{d.a.}$ (Fig. 5), in the city of Shelekhov maximum concentration in the territory of residence of the population, according to calculations amounted to 2 $MPC_{d.a.}$ (Fig. 6).

Section 3.3 presents the results of the calculation of the frequency of exceeding of air quality standards by pollutants, using the semi-empirical model. A result of calculations were detected exceeding for the components corresponding to the list of substances resulting in the calculation of the absolute maximum concentration. Let's present results of calculation for nitrogen dioxode.

As already noted, the calculations have revealed absolute concentrations exceeding the limit concentrations of nitrogen dioxide with peaks in Angarsk, Shelekhov, Bratsk, Zheleznogorsk-Ilimskii, Irkutsk (see. Fig. 4, 5, 6). As for the frequencies of exceeding, the analysis of the results indicates that these territories and their population are exposed to increased concentrations by 610 to 717 hours per month, or 25-29 days. In Shelekhov the maximum frequency of excess is 610 hours (25 days), and there are usually near sources of pollution. In general, all industrial city area exposed to elevated concentrations during 228 hours (9 days) or more, and residential area - from 48 to 216 hours (2 to 9 days) per month (Figure 7). In Angarsk city the maximum frequency of exceeding $MPC_{d.a.}$ for nitrogen dioxide is 717 hours (29 days) in the month, and is also observed near the air pollution sources located in a special industrial zone (Fig. 8). Residential zone in the north of the city and of its central part, close to the production site is exposed to increased concentrations of nitrogen dioxide during 248 hours (10 days) per month. All the rest of the area is influenced for more than 144 hours (6 days) per month. Moreover, the concentration of nitrogen dioxide spread beyond the city boundaries. Analysis of the results of calculations frequencies of exceeding MPCd.a. in the Irkutsk city, showed that increased concentrations of nitrogen dioxide are distributed in an area located outside the city, and the frequency of exceeding these concentrations is 48 hours (2 days) per month (Fig. 9). Maximum of 449 hours (18 days) per month is also observed as the maximum of the absolute concentrations in the northern part of the city.

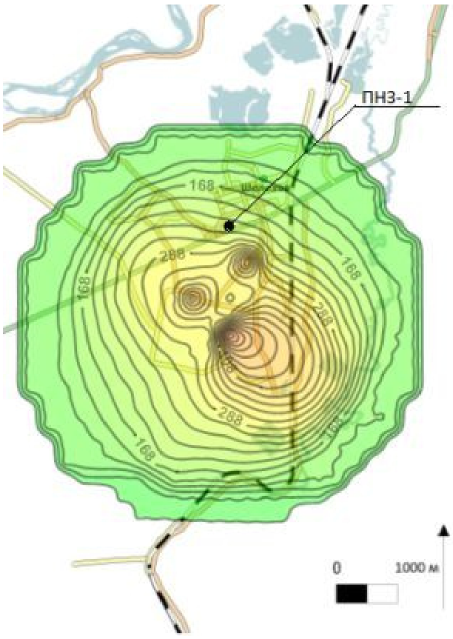

Figure 7 - Schematic map of isolines of frequencies of exceeding MPCd.a. (0.04 mg/m^3) nitrogen dioxide in December in the city of Shelekhov

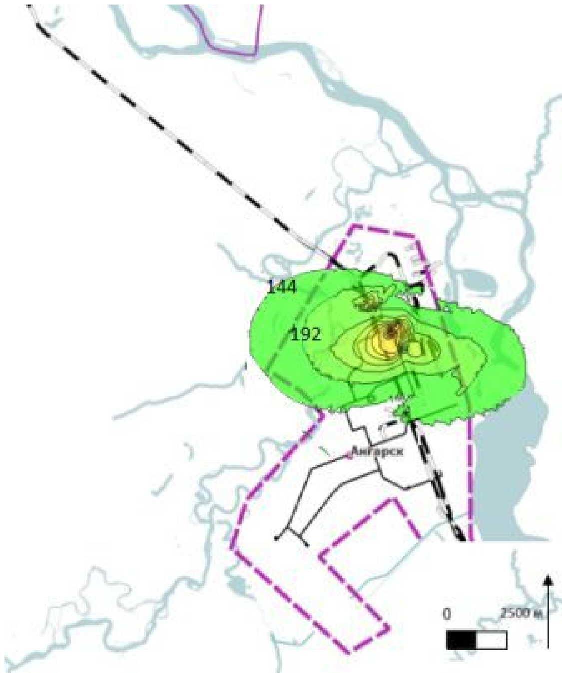

Figure 8 – Schematic map of isolines of frequencies of exceeding MPCd.a. (0.04 mg/m^3) nitrogen dioxide in December in the city of Angarsk

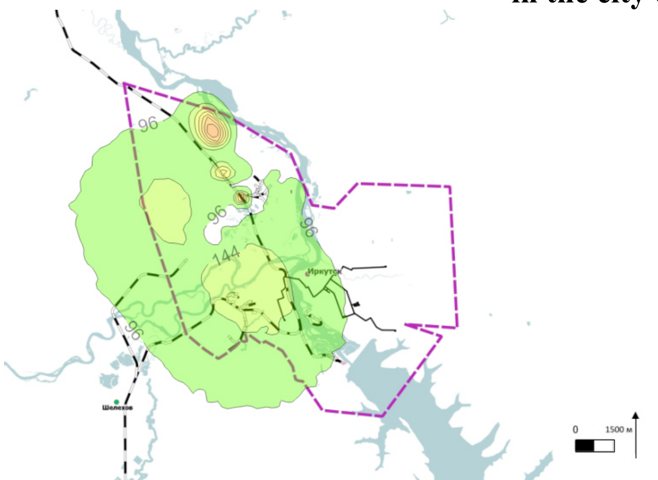

Figure 9 – - Schematic map of isolines of frequencies of exceeding MPCd.a. (0.04 mg/m^3) nitrogen dioxide in December in the city of Irkutsk

Section 3.4. Presents the data of regular observations for territories cities of Irkutsk and Shelekhov provided by the Irkutsk Office for hydro meteorology. Data analysis of nitrogen dioxide concentrations in the Irkutsk city in the period from 2000 to 2015 showed that the most frequently the exceeding of hygienic standards $MPC_{d.a.}$ are observed at POP - 2 – 82 % of total number of observations. Next on the frequency of exceeding are POP-4 – 63 %, POP-23 – 59 % and POP-3 – 57 %.

Based on discrete observations data at 7.00, 13.00 and 19.00, as well as automatic continuous observations, calculated the average values of concentrations (Fig. 10). Analysis of values of deviations and coefficients of variation indicates that the observations and the average concentrations calculated based on them are characterized by satisfactory statistical homogeneity, except for a small number of observations, for example, in December 2001, July 2008, December and July 2010.

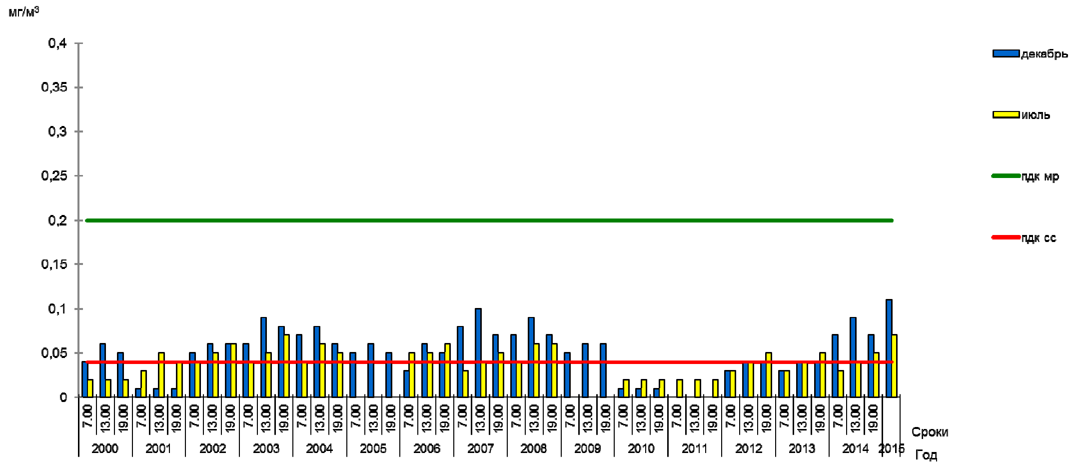

Figure 10 - Dynamics of average concentrations of nitrogen dioxide in December and July on post observations of atmospheric pollution (POP) - 2 - Kirov Square

The heterogeneity in the data is due to the manifestation of the absolute maxima, which observed no more than 1 times in the period under review, for example the maximum concentration in the July 2008 affected the heterogeneity of the data in the reporting period of observation, with an average concentration of 0.04 mg/m^3 of deviation from the mean was 0,06 mg/m^3. Comparison of the average concentration value indicates the predominance of winter concentrations of the summer (Fig. 10), there are certain periods exceeding summer concentrations over the winter, which can be explained by abnormalities of weather.

Comparative analysis of the calculated maximum concentrations and frequencies of exceeding of environmental quality standards at point of location of observation stations (see. Fig. 4) indicates the consistency of the calculated data and in situ measurements (Table. 1, 2).

Table 1 – Summary table of the calculated data and field observations at the point of POP-2

Winter time		Summer time	
The maximum concentration recorded at the POP	The maximum calculated concentrations	The maximum concentration recorded at the POP	The maximum calculated concentrations
0,32 mg/m^3	0,08 mg/m^3	0,34 mg/m^3	0,06 mg/m^3

At the same time, the calculated absolute maximum concentration values and the duration of exceeding was recorded in the northern part of the city, where the current observation posts for air pollution are not available.

Table 2 – Summary table of the calculated data and field observations at the point of POP-2 (based on data for 2015)

Winter time		Summer time	
The duration of exceedances recorded in the PNZ	Calculated duration of exceeding	The duration of exceedances recorded in the PNZ	Calculated duration of exceeding
600 hours	144 hours	622 hours	115 hours

In Shelekhov city the monitoring of nitrogen dioxide are carried out on two stations. Analysis of the data of exceeding standard MPCd.a. showed that the most frequently the exceeding are recorded at POP-1 from 50 to 90% of total numbers of observations. Further, POP-3.

Analysis of deviations and coefficient of variation calculated for the field data showed statistical satisfying homogeneity except for data obtained at 7.00 April 2008, at 7.00 July 2008.

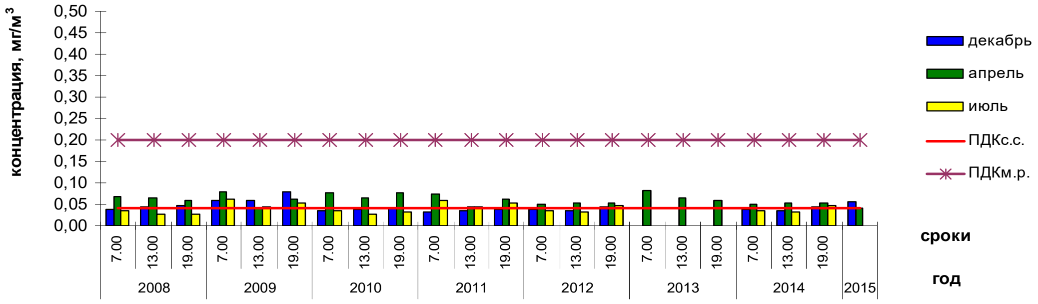

Figure 11 - Dynamics of average concentrations of nitrogen dioxide in December, April and July, the POP-1

Analysis of averaged data showed that in the spring (April), the concentration of nitrogen dioxide exceeds the concentration in winter (Fig. 11). This is because at spring increases the influx of solar radiation as a consequence, photochemical oxidation processes oxides to nitrogen dioxide are accelerated, but emissions remain at the level of the winter months. In July, concentrations often exceed the value of the winter, which is also the cause of the processes described above, as well as the activation of natural sources of pollution, such as forest and peat fires.

Comparative analysis of the calculated maximum concentrations and frequencies of exceeding of environmental quality standards at point of location of observation stations (see. Fig. 6) indicates the consistency of the calculated data and in situ measurements (Table. 3,4).

Table 3 – Summary table of the calculated data and field observations at the point of POP-1

Winter time		Summer time	
The maximum concentration recorded at the POP	The maximum calculated concentrations	The maximum concentration recorded at the POP	The maximum calculated concentrations
0,35 mg/m^3	0,08 mg/m^3	0,22 mg/m^3	0,05 mg/m^3

Table 4 – Summary table of the calculated data and field observations at the point of POP-1 (based on data for 2015)

Winter time		Summer time	
The duration of exceedances recorded in the PNZ	Calculated duration of exceeding	The duration of exceedances recorded in the PNZ	Calculated duration of exceeding
525 hours	216 hours	346 hours	177 hours

Key findings on the third chapter: At most stations in January, the wind is characterized by instability, with the exception of the station: Zheleznogorsk-Ilimskii, Mama, Kirensk; in April wind was characterized by stability at stations Nizhneudinsk, Usolie-Sibirskoe, Kirensk, Cheremkhovo, Sayansk; in June – at stations Usolie-Sibirskoe, Ust'-Ilimsk, Ust'-Kut, Zheleznogorsk-Ilimskii. The most unfavorable conditions for the dispersion are created in January, the best conditions for the scattering are observed in April. The calculation of absolute concentrations showed that in winter time for substances: nitrogen dioxide, sulfer dioxide, inorganic dust, benzo(a) yrene, nitrogen oxide, carbon black concentration peaks can reach values higher than $MPC_{d.a.}$ by 20 times, and the frequency of exceeding is more than 700 hours per month; concentrations in summer are reduced, as well as the frequency of exceeding hygienic standards.

In conclusion the main stages has been summarized and findings that got during work has been formulated:

1. In the study period (January, April, June) in most of the considered stations the wind characterized by instability, except in January, northern regions, and in April and June, the southern and south-eastern areas of the region. In the city of Angarsk, Balagansk, Irkutsk, Shelekhov wind is characterized by instability in all periods of the study, without exception, due to the predominance in the territories of the two wind directions: north-west and south-east in Irkutsk, Angarsk and Shelekhov; north and north-west in Balagansk.
2. Construction of the ellipses of scattering of wind flow, that is a qualitative characteristic of the atmosphere's self-purification, and finding squares of ellipses allowed to reveal that the most unfavorable conditions for the dispersion are created in January, characterized by high repeatability of low wind velocity which conducive to the accumulation of contaminants on the underlying surface; the best conditions for dispersion are formed in April - the month in which wind velocity increases and frequency of low wind velocity decreases in 3-4 times compared with the winter months. However, the increase of wind velocity in spring contributes to additional income of pollutants accumulated in the winter on the underlying surface and the creation of higher concentrations, which is confirmed by the data obtained by the monitoring stations of pollution of atmospheric air.
3. Priority harmful substances, in terms of creating high levels of pollution in the territory of the Irkutsk region, are: nitrogen dioxide and sulfur dioxide, carbon black, inorganic dust with a silicon content of 20-70% and less than 20%, nitrogen oxide, benzo(a)pyrene, oil ash, as well as a number of specific pollutants, such as formaldehyde, fluoride, hydrogen sulfide, and others substances.
4. The calculated absolute concentrations of pollutants released with the emissions from stationary sources of industrial enterprises on the territory of the region varied, but generally indicate excess air quality standards (MPCd.a.) in winter: for nitrogen dioxide 2-20 times; sulfer dioxode –1,5-20 times; inorganic dust (with a silicon content of 20-70 %) – 1,2-20 times, with a silicon content less than 20 % – 1,2-10 times; nitroges oxide – 3-20 times, benzo(a)pyrene – 10-20 times; oil ash – 7,4-20 times.

5. Calculation of frequencies of exceeding the standards for pollutants showed that the duration of action of concentrations in excess of the norm MPCd.a. in December: for nitrogen dioxide from 12 up to 717 hours. (depending on the territory); sulfer dioxode – 22-720 h.; carbon black – 12-712 h.; inorganic dust, with a silicon content of 20-70 % – 12-460 h.; with a silicon content less than 20 % – 12-700 h.; nitroges oxide – 12-720 h.; benzo(a)pyrene –12-750 h.; oil ash – 12-588 h.

6. Calculated absolute concentration and frequency of exceeding the norm MPCd.a. caused by emissions from stationary sources of the industrial enterprises in the summer have smaller values in comparison with those obtained for the winter months, due to, firstly, the reduction of emissions from industrial enterprises, particular power plants, that have the largest contribution to emissions in the territory of the Irkutsk region, and secondly, the change of meteorological conditions conducive to the scattering of pollutants.

7. Mapping of the Irkutsk region by level of of air pollution has revealed areas with the greatest anthropogenic impact on the air basin, including: Irkutsk, Angarsk, Shelekhov, Bratsk, Zima.

8. Comparative analysis of calculation data and data of measurements of monitoring stations for air pollution has revealed coherence of the results, but for the city of Irkutsk, the calculated maximum concentration and frequencies of excess found in areas not equipped by points of systematic observations.

9. Research of dynamics of concentrations of pollutants, their statistical processing has revealed heterogeneity of the data, obtained from observations at the posts of monitoring of atmosphere conditions, which may be the cause of emissions from mobile and natural sources, with a random character.

Thus, as a result of activity of the major sources of pollutants in the Irkutsk region - industrial enterprises, concentration significantly exceeding the standards set for them are generated. One of the tools by means of which possible to control air quality and identify violations in the observance of the established maximum permissible emissions for enterprises, aimed to compliance with the MPC standards, is the organization of a representative network of observations, including undertorch positions in the areas of maximum concentration values, and the frequencies of exceeding the set hygienic standards for pollutants.

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